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(54) **Title:** EFFICIENT VTOL RESOURCE MANAGEMENT IN AN AVIATION TRANSPORT NETWORK

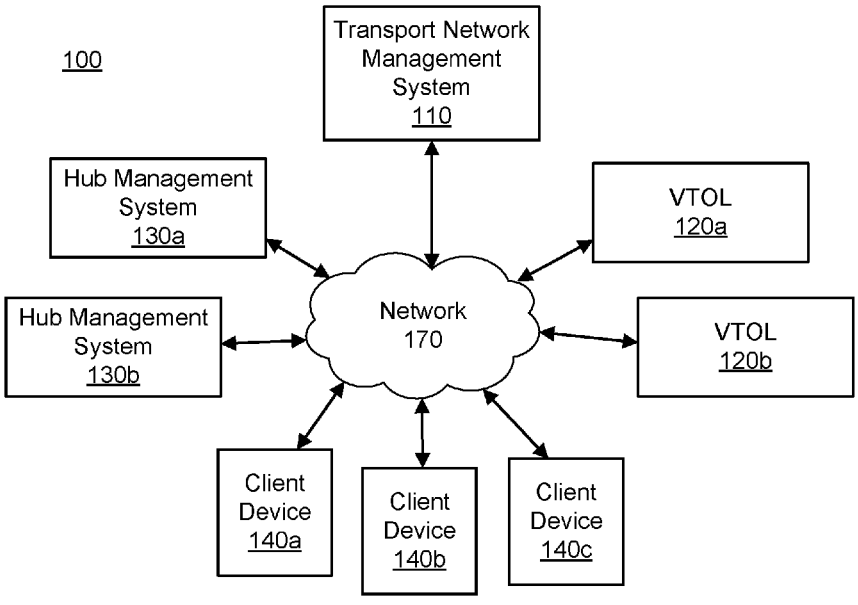

FIG. 1

(57) **Abstract:** A transport network management system identifies a service objective for a plurality of VTOL aircraft and retrieves VTOL data including locations of the plurality of VTOL aircraft. An estimate of demand for transport services to be provided at least in part by one of the VTOL aircraft is generated and routing data for the plurality of VTOL aircraft is determined based on the estimated demand and the service objective. Routing instructions based on the routing data are sent to at least a subset of the VTOL aircraft.

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EFFICIENT VTOL RESOURCE MANAGEMENT IN AN AVIATION TRANSPORT NETWORK

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application No. 62/489,992, filed April 25, 2017, which is incorporated by reference in its entirety.

BACKGROUND

1. TECHNICAL FIELD

[0002] The subject matter described generally relates to aviation transport networks, and in particular to managing a network including ad hoc flights between hubs.

2. BACKGROUND INFORMATION

[0003] There is generally a wide variety of modes of transport available within cities. People may walk, ride a bike, drive a car, take public transit, use a ride sharing service, and the like. However, as population densities and demand for land increase, many cities are increasingly experiencing problems with traffic congestion and the associated pollution. Consequently, there is a need to expand the available modes of transport in ways that may reduce the amount of traffic without requiring the use of large amounts of land.

SUMMARY

[0003a] A method implemented by a computer system to utilize real-time data to dynamically determine charging times of an aircraft to perform on-demand routing, the method comprising: identifying a service objective for a plurality of vertical take-off and landing (VTOL) aircraft; retrieving real-time VTOL data from the plurality of VTOL aircraft, the VTOL data including current locations, battery consumption rates, battery charging rates, and current battery levels of the plurality of VTOL aircraft; generating an estimate of demand for passenger transport services during a given time period; determining, based on the estimate of demand, the current battery levels, and the service objective, a route for each of the plurality of VTOL aircraft, each route specifying a destination, any way points to visit while traveling to the destination, an amount of time to spend charging, and a time to depart; and sending routing instructions to at least a subset of the VTOL aircraft, the routing instructions based on the determined route for each of the VTOL aircraft in the subset, wherein determining the amount of time to spend charging for each of the plurality of VTOL aircraft includes processing the current battery levels, the consumption rates, and the charging

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rates of the battery of the VTOL aircraft, and wherein the routing instructions direct the flight of at least one of the VTOL aircraft in the subset to charge for the amount of time.

[0003b] A computer program comprising machine-readable instructions that, when executed by one or more processors, causes the one or more processors to perform operations to utilize real-time data to dynamically determine charging times of an aircraft to perform on-demand routing, the operations comprising: identifying a service objective for a plurality of vertical take-off and landing (VTOL) aircraft; retrieving real-time VTOL data from the plurality of VTOL aircraft, the VTOL data including current locations, battery consumption rates, battery charging rates, and current battery levels of the plurality of VTOL aircraft; generating an estimate of demand for passenger transport services during a given time period; determining, based on the estimate of demand, the current battery levels, and the service objective, a route for each of the plurality of VTOL aircraft, each route specifying a destination, any way points to visit while traveling to the destination, an amount of time to spend charging, and a time to depart; and sending routing instructions to at least a subset of the VTOL aircraft, the routing instructions based on the route for each of the plurality of VTOL aircraft in the subset, wherein determining the amount of time to spend charging for each of the plurality of VTOL aircraft includes processing the current battery levels, the consumption rates, and the charging rates of the battery of the VTOL aircraft, and wherein the routing instructions direct the flight of at least one of the VTOL aircraft in the subset to charge for the amount of time.

[0003c] A computer system to utilize real-time data to dynamically determine charging times of an aircraft to perform on-demand routing, the computer system comprising: one or more hardware processors; and a computer-readable storage medium comprising executable computer program code, the computer program code when executed causing the one or more processors to perform operations including: identifying a service objective for a plurality of vertical take-off and landing (VTOL) aircraft; retrieving real-time VTOL data from the plurality of VTOL aircraft, the VTOL data including current locations, battery consumption rates, battery charging rates, and current battery levels of the plurality of VTOL aircraft; generating an estimate of demand for passenger transport services during a given time period; determining battery levels of each of the plurality of VTOL aircraft; determining, based on the estimate of demand, the battery levels, and the service objective, a route for each of the plurality of VTOL aircraft, each route specifying a destination, any way points to visit while traveling to the destination, an amount of time to spend charging,

and a time to depart; and sending routing instructions to at least a subset of the VTOL aircraft, the routing instructions based on the routes for each of the VTOL aircraft in the subset, wherein determining the amount of time to spend charging for each of the plurality of VTOL aircraft includes processing the current battery levels, the consumption rates, and the charging rates of the battery of the VTOL aircraft, and wherein the routing instructions direct the flight of at least one of the VTOL aircraft in the subset to charge for the amount of time.

[0003d] A method implemented by a computer system to utilize real-time data to dynamically determine charging times of an aircraft to perform on-demand routing, the method comprising: determining locations of a plurality of vertical take-off and landing (VTOL) aircraft; determining a plurality of passenger transportation requests, each passenger transportation request for travel from a respective origin location to a respective destination location; determining, in real-time, a battery consumption rate, a battery charging rate, and a current battery level for each of the plurality of VTOL aircraft; providing the plurality of passenger transportation requests, the locations, and the current battery levels to a network flow model, the network flow model configured to concurrently determine routing data for each of the plurality of VTOL aircraft by modeling different flows of the plurality of VTOL aircraft through a transportation network; and sending routing instructions to at least a subset of the VTOL aircraft, the routing instructions based on each VTOL aircraft's respective routing data, wherein the routing instructions direct the flight of at least one of the VTOL aircraft in the subset to charge for an amount of time, and wherein determining the amount of time to spend charging for at least one of the VTOL aircraft in the subset includes processing the current battery levels, the consumption rates, and the charging rates of the battery of the VTOL aircraft.

[0003e] A computer program comprising machine-readable instructions that, when executed by one or more processors, causes the one or more processors to perform operations to utilize real-time data to dynamically determine charging times of an aircraft to perform on-demand routing, the computer program comprising: determining locations of a plurality of vertical take-off and landing (VTOL) aircraft; determining a plurality of passenger transportation requests, each passenger transportation request for travel from a respective origin location to a respective destination location; determining, in real-time, a battery consumption rate, a battery charging rate, and a current battery level for each of the plurality of VTOL aircraft; providing the plurality of passenger transportation requests, the locations, and the current battery levels to a network flow model, the network flow model configured to

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concurrently determine routing data for each of the plurality of VTOL aircraft by modeling different flows of the plurality of VTOL aircraft through a transportation network; and sending routing instructions to at least a subset of the VTOL aircraft, the routing instructions based on each VTOL aircraft's respective routing data, wherein the routing instructions direct the flight of at least one of the VTOL aircraft in the subset to charge for an amount of time, and wherein determining the amount of time to spend charging for at least one of the VTOL aircraft in the subset includes processing the current battery levels, the consumption rates, and the charging rates of the battery of the VTOL aircraft.

[0003f] A computer system to utilize real-time data to dynamically determine charging times of an aircraft to perform on-demand routing, the computer system comprising: one or more hardware processors; and a computer-readable storage medium comprising executable computer program code, the computer program code when executed causing the one or more hardware processors to perform operations including: determining locations of a plurality of vertical take-off and landing (VTOL) aircraft; determining a plurality of passenger transportation requests, each passenger transportation request for travel from a respective origin location to a respective destination location; determining, in real-time, a battery consumption rate, a battery charging rate, and a current battery level for each of the plurality of VTOL aircraft; providing the plurality of passenger transportation requests, the locations, and the current battery levels to a network flow model, the network flow model configured to concurrently determine routing data for each of the plurality of VTOL aircraft by modeling different flows of the plurality of VTOL aircraft through a transportation network; and sending routing instructions to at least a subset of the VTOL aircraft, the routing instructions based on each VTOL aircraft's respective routing data, wherein the routing instructions direct the flight of at least one of the VTOL aircraft in the subset to charge for an amount of time, and wherein determining the amount of time to spend charging for at least one of the VTOL aircraft in the subset includes processing the current battery levels, the consumption rates, and the charging rates of the battery of the VTOL aircraft.

[0003g] Any discussion of documents, acts, materials, devices, articles or the like which has been included in the present specification is not to be taken as an admission that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the present disclosure as it existed before the priority date of each of the appended claims.

[0003h] Throughout this specification the word "comprise", or variations such as

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"comprises" or "comprising", will be understood to imply the inclusion of a stated element, integer or step, or group of elements, integers or steps, but not the exclusion of any other element, integer or step, or group of elements, integers or steps.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004] FIG. 1 is a high-level block diagram illustrating a computing environment associated with a transport network, according to one embodiment.

[0005] FIG. 2 is a high-level block diagram illustrating the transport network management system shown in FIG. 1, according to one embodiment.

[0006] FIG. 3 is a high-level block diagram illustrating the demand estimation subsystem shown in FIG. 2, according to one embodiment.

[0007] FIG. 4 is a high-level block diagram illustrating the candidate hub identification subsystem shown in FIG. 2, according to one embodiment.

[0008] FIG. 5 is a high-level block diagram illustrating the hub optimization subsystem shown in FIG. 2, according to one embodiment.

[0009] FIG. 6 is a high-level block diagram illustrating the route optimization subsystem shown in FIG. 2, according to one embodiment.

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[0010] FIG. 7 is a high-level block diagram illustrating an example of a computer suitable for use in the computing environment of FIG. 1, according to one embodiment.

[0011] FIG. 8 is a flow-chart illustrating a method for planning and managing a transport network, according to one embodiment.

[0012] FIG. 9 is a flow-chart illustrating a method for determining routing within a transport network, according to one embodiment.

DETAILED DESCRIPTION

[0013] The figures and the following description describe certain embodiments by way of illustration only. One skilled in the art will readily recognize from the following description that alternative embodiments of the structures and methods may be employed without departing from the principles described. Reference will now be made to several embodiments, examples of which are illustrated in the accompanying figures. It is noted that wherever practicable similar or like reference numbers are used in the figures to indicate similar or like functionality.

OVERVIEW

[0014] Air travel within cities has been limited compared to ground travel. Air travel can have a number of requirements making intra-city air travel difficult. For instance, aircraft can require significant resources such as fuel and infrastructure (e.g., runways), produce significant noise, and require significant time for boarding and alighting, each presenting technical challenges for achieving larger volume of air travel within cities or between neighboring cities. However, providing such air travel may reduce travel time over purely ground-based approaches as well as alleviate problems associated with traffic congestion.

[0015] Vertical take-off and landing (VTOL) aircraft provide opportunities to incorporate aerial transportation into transport networks for cities and metropolitan areas. VTOL aircraft require much less space to take-off and land relative to traditional aircraft. In addition, developments in battery technology have made electric VTOL aircraft technically and commercially viable. Electric VTOL aircraft may be quieter than aircraft using other power sources, which further increases their viability for use in built-up areas where noise may be a concern.

[0016] In a planning phase, estimates of demand are used to identify candidate locations for hubs within a geographic region at which VTOL aircraft take-off and land. The demand estimates may also be used to narrow down the candidate locations to a selected

subset of locations that best meets some predetermined objective (e.g., maximizing VTOL coverage, maximizing reductions in travel time, etc.). Flow of VTOL aircraft and people through the transport can then be simulated to gain insight into the proposed aviation transport network and further refine its configuration to better meet specified objectives.

[0017] Once a set of hubs have been built and a fleet of VTOL aircraft are in operation, demand prediction and network optimization processes may be used to coordinate provision of transport services. By optimizing the use of the VTOL aircraft fleet, the total power usage and wear and tear may be reduced while still saving riders significant amounts of time relative to ground-based transportation.

[0018] In one embodiment, a transport network management system 110 identifies a service objective for a plurality of VTOL aircraft and retrieves VTOL data including locations of the plurality of VTOL aircraft. An estimate of demand for transport services to be provided at least in part by one of the VTOL aircraft is generated and routing data for the plurality of VTOL aircraft is determined based on the estimated demand and the service objective. Routing instructions based on the routing data are sent to at least a subset of the VTOL aircraft.

EXAMPLE SYSTEM ENVIRONMENT

[0019] FIG. 1 illustrates one embodiment of a computing environment 100 associated with an aviation transport network. In the embodiment shown in FIG. 1, the computing environment 100 includes a transport network management system 110, a set of VTOL aircraft 120a, 120b, a set of hub management systems 130a, 130b, and a set of client devices 140a, 140b, 140c, all connected via a network 170. Where multiple instances of a type of entity are depicted and distinguished by a letter after the corresponding reference numeral, such entities shall be referred to herein by the reference numeral alone unless a distinction between two different entities of the same type is being drawn. In other embodiments, the computing environment 100 contains different and/or additional elements. In addition, the functions may be distributed among the elements in a different manner than described. For example, the hub management systems 130 may be omitted with information about the hubs stored and updated at the transport network management system 110.

[0020] The transport network management system 110 assists in the planning and design of the transport network. In one embodiment, the transport network management system 110 estimates demand for transport services, suggests locations for VTOL hubs to help meet that demand, and simulates the flow of riders and VTOL aircraft between the hubs

to assist in network planning. Embodiments of the transport network management system 110 are described in greater detail below, with reference to FIGS. 2 through 6.

[0021] The transport network management system 110 may also coordinate transport services once a set of VTOL hubs are operational. The transport network management system 110 may pair users who request transport services (riders) with specific VTOL aircraft 120. The transport network management system 110 may also interact with ground-based transportation to coordinate travel services. For example, the transport network management system 110 may be an extension of an existing transport services coordinator, such as a ridesharing service.

[0022] In one embodiment, the transport network management system 110 treats a journey involving a VTOL aircraft 120 as having three legs: (1) from the rider's initial location to a first hub; (2) from the first hub to a second hub in a VTOL; and (3) from the second hub to the rider's destination. The first and third legs may be walking or provided by ground transportation, such as a ride-sharing service. The transport network management system 110 provides routing information to VTOL aircraft 120, such as what time to leave a current hub, which hub to fly to after departure, way points along the way, how long to spend charging before departure or on arrival, and the identity of individuals to carry. The transport network management system 110 may also direct certain VTOL aircraft 120 to fly between hubs without riders to improve fleet distribution (referred to as "deadheading").

[0023] The VTOL aircraft 120 are vehicles that fly between hubs in the transport network. A VTOL aircraft 120 may be controlled by a human pilot (inside the vehicle or on the ground) or it may be autonomous. In one embodiment, the VTOL aircraft 120 are battery-powered aircraft that use a set of propellers for horizontal and vertical thrust. The configuration of the propellers enables the VTOL aircraft to take-off and land vertically (or substantially vertically). For convenience, the various components of the computing environment 100 will be described with reference to this embodiment. However, other types of aircraft may be used, such as helicopters, planes that take-off at angles other than vertical, and the like. The term VTOL should be construed to include such vehicles.

[0024] A VTOL aircraft 120 may include a computer system that communicates status information (e.g., via the network 170) to other elements of the computing environment 100. The status information may include current location, current battery charge, potential component failures, and the like. The computer system of the VTOL aircraft 120 may also receive information, such as routing information and weather information. Although two

VTOL aircraft 120 are shown in FIG. 1, a transport network can include any number of VTOL aircraft.

[0025] A hub management systems 130 provides functionality at a hub in the transport network. A hub is a location at which VTOL aircraft 120 are intended to land (and take-off). Within a transport network, there may be different types of hub. For example, a hub in a central location with a large amount of rider throughput might include sufficient infrastructure for sixteen (or more) VTOL aircraft 120 to simultaneously (or almost simultaneously) take off or land. Similarly, such a hub might include multiple charging stations for recharging battery-powered VTOL aircraft 120. In contrast, a hub located in a sparely populated suburb might include infrastructure for a single VTOL aircraft 120 and have no charging station. The hub management system 130 may be located at the hub or remotely and be connected via the network 170. In the latter case, a single hub management system 130 may serve multiple hubs.

[0026] In one embodiment, a hub management system 130 monitors the status of equipment at the hub and reports to the transport network management system 110. For example, if there is a fault in a charging station, the hub management system 130 may automatically report that it is unavailable for charging VTOL aircraft 120 and request maintenance or a replacement. The hub management system 130 may also control equipment at the hub. For example, in one embodiment, a hub includes one or more launch pads that may move from a takeoff/landing position to embarking/disembarking position. The hub management system 130 may control the movement of the launch pad (e.g., in response to instructions received from transport network management system 110 and/or a VTOL aircraft 120).

[0027] The client devices 140 are computing devices with which users may arrange transport services within the transport network. Although three client devices 140 are shown in FIG. 1, in practice, there may be many more (e.g., thousands or millions of) client devices connected to the network 170. In one embodiment, the client devices 140 are mobile devices (e.g., smartphones, tablets, etc.) running an application for arranging transport services. A user provides a pickup location and destination within the application and the client device 140 sends a request for transport services to the transport network management system 110. Alternatively, the user may provide a destination and the pickup location is determined based on the user's current location (e.g., as determined from GPS data for the client device 140).

[0028] Regardless of how they are generated, the transport network management system 115 may determine how to service transport requests. In one embodiment, a transport

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request can be serviced by a combination of ground-based and aerial transportation. The transport network management system 110 sends information about how the request will be serviced to the user's client device 140 (e.g., what vehicle the user should get into, directions on where to walk, if necessary, etc.).

[0029] The network 170 provides the communication channels via which the other elements of the networked computing environment 100 communicate. The network 170 can include any combination of local area and/or wide area networks, using both wired and/or wireless communication systems. In one embodiment, the network 170 uses standard communications technologies and/or protocols. For example, the network 170 can include communication links using technologies such as Ethernet, 802.11, worldwide interoperability for microwave access (WiMAX), 3G, 4G, code division multiple access (CDMA), digital subscriber line (DSL), etc. Examples of networking protocols used for communicating via the network 170 include multiprotocol label switching (MPLS), transmission control protocol/Internet protocol (TCP/IP), hypertext transport protocol (HTTP), simple mail transfer protocol (SMTP), and file transfer protocol (FTP). Data exchanged over the network 170 may be represented using any suitable format, such as hypertext markup language (HTML) or extensible markup language (XML). In some embodiments, all or some of the communication links of the network 170 may be encrypted using any suitable technique or techniques.

TRANSPORT NETWORK PLANNING

[0030] FIG. 2 illustrates one embodiment of the transport network management system 110. In the embodiment shown in FIG. 2, the transport network management system 110 includes a demand estimation subsystem 210, a candidate hub identification subsystem 220, a hub optimization subsystem 230, and a route optimization subsystem 240. In other embodiments, the transport network management system 110 contains different and/or additional elements. In addition, the functions may be distributed among the elements in a different manner than described. For example, although the transport network management system 110 is depicted as connected to the network 170, in some embodiments it is used for initial planning of the transport network and need not be connected to the other depicted components.

[0031] The demand estimation subsystem 210 predicts demand for transport services in a geographic region. The predicted demand may be provided as input to the other subsystems to assist in the planning of the transport network. In one embodiment, the demand estimation

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subsystem 210 initially predicts demand based on usage data for one or more existing ground-based transportation services in the geographic region. The input may be a geographic region (e.g., a city) and time period, and the predicted demand may be a corresponding set of hypothetical transport requests, each including an origin, destination, and time. Where planning continues after the transport network becomes operational (e.g., where a first set of hubs are built and an expansion including adding additional hubs is planned), the model for predicting demand may be updated over time based on usage data that includes flights between hubs in the transport network, as such data becomes available. Various embodiments of the demand estimation subsystem are described in greater detail below, with reference to FIG. 3.

[0032] The candidate hub identification subsystem 220 identifies a set of candidate locations for hubs within the geographic region. In one embodiment, the candidate hub identification subsystem 220 provides an interface with which a user, such as a transport network designer, can manually select candidate locations for hubs (e.g., by providing an address, GPS co-ordinates, clicking on the location on a map, etc.). Alternatively or additionally, the candidate hub identification subsystem 220 may automatically identify candidate locations based on predicted demand (e.g., as produced by the demand estimation subsystem 210). Various embodiments of the candidate hub identification subsystem 220 are described in greater detail below, with reference to FIG. 4.

[0033] The hub optimization subsystem 230 takes the set of candidate locations for hubs and selects a subset of the locations at which hubs should actually be positioned based on the predicted demand. In one embodiment, the hub optimization subsystem 230 identifies an initial group of hub positions to make the transport network operational and one or more additional groups to be added later to improve the coverage of the network. The hub optimization subsystem 230 may also recommend a type for each hub (e.g., indicating a number of landing pads, a number of chargers, a number of VTOL aircraft storage bays, and the like). Various embodiments of the hub optimization subsystem 230 are described in greater detail below, with reference to FIG. 5.

[0034] The output from the hub optimizations subsystem 230 may be fed into the route optimization subsystem 240. The coverage provided by the hubs identified by the hub optimization subsystem 230 provides an upper bound for throughput of the transport network. In other words, it is the maximum throughput achievable by placing hubs at the selected location assuming all qualifying transport requests are served by VTOL aircraft 120. However, this upper bound may not be realized as it does not consider whether a VTOL

aircraft 120 will be available to service any given transport request. The route optimization subsystem 240 models the flow of VTOL aircraft 120 and riders through the transport network to determine how to manage the fleet of VTOL aircraft to realize close to the maximum throughput. Various embodiments of the route optimization subsystem 240 are described in greater detail below, with reference to FIG. 6.

[0035] FIG. 3 illustrates one embodiment of the demand estimation subsystem 210. The demand estimation subsystem 210 predicts demand for transport services within a geographic region. In the embodiment shown in FIG. 3, the demand estimation subsystem 210 includes an initial model module 310, a demand prediction module 320, a model update module 330, and a demand data store 340. In other embodiments, the demand estimation subsystem 210 contains different and/or additional elements. In addition, the functions may be distributed among the elements in a different manner than described. For example, in some embodiments, the demand estimation subsystem 210 is used during planning of the transport network to generate an initial demand model and the model update module 330 may be omitted.

[0036] The initial model module 310 generates a model to predict demand for VTOL services within a geographic region. The model may be built using historical travel data including requests for transport services over a long distance within the geographic region using ground-based transportation (e.g., via a ride sharing service) as a proxy for demand for VTOL demand. The historical travel data may be aggregated from multiple sources. In one embodiment, a request is considered long-distance where the Haversine distance between the origin and destination is between 20 and 100 miles. The initial model module 310 may consider any such requests as being within the geographic region if either the origin or destination is within a given distance (e.g., 120 miles) of a predetermined point (e.g., a center point of the geographic region). The predetermined point and given distance may be selected by the user. Alternatively, the user may define a geofence and only requests for which the origin or destination (or both) are within the geofence are considered. In other embodiments, other ways of determining which requests are considered to be within the geographic region and candidates for servicing with a VTOL aircraft 120 may be used.

[0037] In another embodiment, the initial model module 310 starts with a single estimate based on the historical travel data and uses a stochastic model (e.g., a two-phase stochastic model) to generate a more robust solution that accounts for multiple scenarios. A list of two or more scenarios are defined, each having a corresponding probability that it will occur. In the first phase, a set of hub locations are selected (e.g., as described below, with

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reference to FIGS. 4 and 5). The initial model module 310 then simulates servicing the predicted demand in view of the different scenarios and the corresponding probabilities. Thus, when the transport network is operational, the demand estimation subsystem 210 may analyze current demand data and compare it to the various scenarios to identify which is likely occurring. The demand estimation subsystem 210 may then generate new or updated predictions of future demand based on the identified scenario. The model can also be refined to be more amenable to bad realizations of outcomes. For example, one configuration choice for the transport network might result on average in servicing a greater number of transport requests by VTOL 120 across all scenarios, but in one low probability scenario, the number of requests serviced by VTOL is very low. It may be preferable to select a second configuration in which the average number of requests serviced by VTOL 120 across all scenarios is lower, but there is no scenario where the level of service drops significantly below the average.

[0038] The demand prediction module 320 applies the model to predict demand for VTOL services in the geographic region during some time period. In one embodiment, the user selects a start and end time for which a prediction is desired. Inputs to the model may include: current population of the geographic region, expected population growth of the geographic region, socioeconomics, locations of businesses and other entities (e.g., transport requests may be more often requested to and from airports, bars, venues, college campuses, etc.), and information about the cost, availability, and duration of other means of transport within the geographic region. If the transport network is already operational, the inputs may also include requests for transport services for the time period that have already been received and/or information about historical demand for transport services. The demand prediction module 320 may apply machine-learning techniques to learn how current inputs (e.g., time of day, day of the week, date, weather, special events, number and distribution of requests for transport services already received for the time period, planned outages or limitations for other modes of transport, and the like) may be mapped to future demand.

[0039] As described previously, the output from the model is a set of hypothetical transport requests that are candidates for being serviced at least in part with a VTOL aircraft 120, each including an origin, destination, and time. A request may be considered eligible for servicing by a VTOL aircraft 120 if it would reduce the total travel time by a threshold amount (e.g., 40%) over servicing the request entirely with ground-based transportation. In one embodiment, the demand estimation module 320 periodically (e.g., every minute, every

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five minutes, etc.) estimates demand for a future window of time (e.g., the next hour, the next four hours, the next day, etc.).

[0040] The model update module 330 updates the model used to predict demand as new data becomes available. In one embodiment, once the aviation transport network is operational, the model update module 330 combines the historical travel data derived from ground-based services with travel data derived from requests actually serviced by VTOL aircraft 120. The VTOL services data may be weighted more heavily than the historical data to reflect the fact that it relates to actual VTOL demand rather than a proxy. For example, the transport network management system 110 may see an increase in requests for transport services over long-distances as the lower travel times that result from VTOL aircraft availability increase the attractiveness of long-distance travel to riders.

[0041] The demand data store 340 is one or more computer-readable media configured to store demand data. Although it is depicted as a single entity within the demand estimation subsystem 210, it may be spread across multiple computing devices. For example, the demand data store 340 may be a distributed database that the demand estimation subsystem 210 accesses remotely via the network 170. In one embodiment, the demand data store 340 stores the historical demand data used to build the initial model as well as the data describing actual VTOL services that may be used to update the model. The demand data store 340 may also store the model itself. In some embodiments, the transport network management system 110 serves multiple geographic areas and the demand data store 340 stores different models for each geographic area. Multiple versions of each model may also be stored (e.g., to allow the demand estimation subsystem 210 to roll back to an earlier version if an updated model is found to be less accurate).

[0042] FIG. 4 illustrates one embodiment of the candidate hub identification subsystem 220. The candidate hub identification subsystem 220 identifies candidate locations for hubs at which VTOL aircraft 120 may take off and land. In the embodiment shown in FIG. 4, the candidate hub identification subsystem 220 includes a parameter selection module 410, a candidate selection module 420, a candidate visualization module 430, and a candidate hub store 440. In other embodiments, candidate hub identification subsystem 220 contains different and/or additional elements. In addition, the functions may be distributed among the elements in a different manner than described. For example, some embodiments may omit the candidate visualization module 430 and corresponding functionality.

[0043] The parameter selection module 410 provides a user interface for selecting parameters to be used in identifying candidate locations for hubs. In one embodiment, the

parameters include the total number of candidate locations to identify, locations that must be considered candidates (e.g., by providing GPS coordinates, etc.), locations that cannot be considered (e.g., by defining a geofence around an excluded area). Alternatively, one or more of the parameters may be predetermined. For example, the number of candidate hubs may be constrained to a fixed value (e.g., 100).

[0044] The candidate selection module 420 identifies a set of candidate locations for hubs based on estimated demand (e.g., as produced by the demand estimation subsystem 210) and the selected parameters. In one embodiment, the candidate selection module 420 applies a k-means clustering algorithm to the origins and destinations of the hypothetical transport requests generated by the demand estimation subsystem 210. In the algorithm, k may be set to the total number of candidate locations desired or the total number less the number of candidate locations the user has indicated must be included. The candidate selection module 420 identifies the centroid of each cluster as a candidate location for a hub. In other embodiments, other approaches may be used to identify candidate locations based on the estimated demand.

[0045] The candidate visualization module 430 (if included) presents the candidate locations to the user. In one embodiment, the candidate visualization module displays a map of the geographic region with the candidate locations overlaid (e.g., as black circles, etc.). The candidate visualization module 430 may allow the user to add additional locations that must be considered, remove candidate locations generated by the candidate selection module 420, and/or change the location of candidates. The visualization may also assist the user in modifying the parameters and rerunning the process of identifying candidate locations.

[0046] The candidate hub store 440 is one or more computer-readable media configured to store the candidate locations for hubs. It may also store a local copy of the data used the candidate hub identification subsystem 220, such as estimated demand data. Although it is depicted as a single entity within the candidate hub identification subsystem 220, it may be spread across multiple computing devices.

[0047] FIG. 5 illustrates one embodiment of the hub optimization subsystem 230. The hub optimization subsystem 230 assists with selecting which candidate locations for hubs to select to build hubs. In the embodiment shown in FIG. 5, the hub optimization subsystem 230 includes a parameter selection module 510, a hub selection module 520, a hub classification module 530, a hub visualization module 540, and a hubs store 550. In other embodiments, the hub optimization subsystem 230 contains different and/or additional elements. In addition, the functions may be distributed among the elements in a different

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manner than described. For example, some embodiments may omit the hub visualization module 540 and corresponding functionality.

[0048] Similar to its counterpart in the candidate hub identification subsystem 220, the parameter selection module 510 provides a user interface for selecting parameters used in determining which candidate locations should be selected for building actual hubs. In one embodiment, the user may select between two objectives: maximizing the number of riders whose requests are covered by a hub or maximizing the total time saved using VTOL aircraft 120. The user may select a fixed number of hub locations (e.g., twenty-five) that should selected or the number may be left to be determined by the optimization objective. Similarly, the user may identify a number (or range) of hubs of different types that should be included (e.g., five large hubs with the capacity for sixteen VTOL aircraft 120, charging equipment, and maintenance services; ten medium hubs with the capacity for four VTOL aircraft, and charging equipment; and ten small hubs with the capacity for one VTOL aircraft). The parameter selection module 510 may also enable the user to identify multiple phases of construction, which may have different objectives. For example, a first phase might be restrained to twenty-five hubs with the goal of maximizing the number of riders served and a second phase might involve building another fifteen hubs with the goal of maximizing the amount of time saved. In other embodiments, different objectives or combinations of objectives may be set.

[0049] The parameter selection module 510 may also enable the user to set other parameters regarding the transport network. For example, in one embodiment the user can set a minimum distance (e.g., a Haversine distance) between hubs, a maximum distance VTOL aircraft 120 can travel without recharging, the rate at which a VTOL aircraft battery charges, whether the battery can be swapped (and how long it takes), a maximum airspeed of the VTOL aircraft, time taken to take off and land, time taken to load and unload riders, a threshold timesaving for a request to be considered eligible for service by VTOL, a number of riders a VTOL aircraft may carry at once, and curfew times (e.g., a period at night when VTOL aircraft are not allowed to fly), and the like. Some or all of these parameters may be preset and unavailable to be changed by the user. In some embodiments, the transport network may include more than one type of VTOL aircraft 120 and the user may provide the parameters for each type. Alternatively, the user may just select the type or types of VTOL aircraft 120 from a list (e.g., in a drop-down menu) and the parameter selection module 510 retrieves the corresponding information (maximum airspeed, maximum distance without recharging, number of riders that can be carried, etc.) from a data store.

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[0050] The hub selection module 520 selects a subset of the candidate locations as recommended locations to construct hubs. In various embodiments, the hub selection module 520 retrieves predicted demand data (e.g., from the demand data store 340) that includes a set of hypothetical requests for transport services. Each hypothetical request includes an origin and a destination. The hub selection module 520 identifies a subset of the candidate hubs that meets all of the provided parameters and best meets the selected objective.

[0051] In one embodiment, for a given subset of candidate hubs, the hub selection module 520 determines how to service each request. A request will either be serviced by a single leg on the ground (e.g., using a ridesharing service) or a set of three legs where the middle leg is serviced by a VTOL aircraft 120. The first and third legs are ground-based, and can be walking legs or serviced by ground-based transportation. A given request may be a candidate for servicing by a VTOL aircraft 120 if the resulting time saving exceeds a threshold (e.g., 40%) over servicing the request entirely with ground-based transportation. The time taken for a VTOL-serviced leg may be estimated by multiplying the Haversine distance by a constant scaling factor (e.g., 1.42) to get a leg distance and assuming a typical airspeed (e.g., 170 miles per hour). When a request is serviced by VTOL aircraft 120, the first and third legs may be considered candidates for being walking legs if they are less than a threshold distance (e.g., if the Haversine distance is less than 500 meters).

[0052] The hub selection module 520 may treat selection of the subset of hubs as a binary optimization problem. For example, define H as the set of candidate hubs each of which are either selected or not and R as the set of riders, indexed by r, each having a set of paths P(r). A path is an itinerary that contains a VTOL-serviced leg. Based on this, one may define three further variables:

1) For each candidate hub, $h \in HH$, zz_h indicates whether that hub is chosen ($zz_h = 1$) or not ($zz_h = 0$).
2) $xx_{rr,pp}$ is a binary variable that equals 1 if rider r is assigned to path p from P(r) and 0 otherwise.
3) To account for the fact that not all requests may be covered depending upon the hubs chosen, yy_{rr} is another binary variable that equals 1 when rider r is not assigned a VTOL path and 0 otherwise.

[0053] Assigning rider r to path p takes incurs some duration savings $\pi_{rr,pp}$. Formally this is the reduction in minutes relative to taking ground-based transportation and is measured as follows:

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$$\tau_{r,p} = T(o(r), d(r)) - [T(o(r), h_{dep}(p)) + VTOL(h_{dep}(p), h_{arr}(p)) + T(h_{arr}(p), d(r)) + \alpha]$$

Where $TT(ii, jj)$ is the estimated driving time from location i to j, $VVTTVVVV(ii, jj)$ is the estimated duration of taking a VTOL aircraft 120 from hub i to hub j, and $\alpha\alpha$ is a fixed number applied to all VTOL-serviced itineraries consisting of a load time, take off time, landing time, and unload time. Moreover $oo(rr)$ and $dd(rr)$ represent the origin and destination of rider r and $h_{dddddpp}(pp)$ and $h_{aarrrr}(pp)$ represent the departure and arrival hubs for path p. To encourage servicing of as many requests as possible by VTOL 120, a penalty $\lambda\lambda$ may be applied for any request not covered by a VTOL route. This leads to the following formulation of the optimization problem:

$$\max \sum_{r \in R} \left(\sum_{p \in P(r)} \tau_{r,p} x_{r,p} \right) - \lambda y_r \tag{1}$$

$$\text{s.t.} \quad \sum_{p \in P(r)} x_{r,p} + y_r = 1 \quad \forall r \in R \tag{2}$$

$$\sum_{h \in H} z_h = \min\{|H|, b\} \tag{3}$$

$$x_{r,p} \leq \frac{1}{2} z_i + \frac{1}{2} z_j \quad \forall r \in R, \forall (i,j) \in P(r) \tag{4}$$

$$z_i + z_j \leq 1 \quad \forall (i,j) \in \mathcal{C} \tag{5}$$

$$x_{r,p} \in \{0,1\} \quad \forall r \in R, \forall p \in P(r)$$

$$y_r \in \{0,1\} \quad \forall r \in R$$

$$z_h \in \{0,1\} \quad \forall h \in H$$

[0054] Here, constraint (1) seeks to maximize total duration savings for all riders in the network jointly by favoring assigning riders to itineraries with large time savings (first term) and by penalizing requests not serviced by VTOL aircraft 120 (second term). Constraint (2) ensures all riders are assigned either to a VTOL itinerary or are to remain on the ground. Constraint (3) ensures the number of hubs selected do not exceed the maximum allowable. Constraint (4) ensures riders are assigned only to itineraries for which both departure and arrival hubs are included in the selected subset. Notice that if either origin (i) or destination (j) hub are closed for path p this forces $xx_{rr,pp}$ to be 0. Constraint (5) ensures that for any hubs that are too close together in a set, $\mathcal{C}$ at most one of these hubs is chosen. This set of constraints may be solved by an integer program optimization solver to identify a subset of

the candidate hubs that meets the applied constraints and achieves the selected objective. Note that the balance between total time savings and VTOL aircraft 120 utilization may be altered by modifying the magnitude of the penalty applied for requests not serviced by a VTOL aircraft (e.g., by changing the value of λ). In other embodiments, other optimization processes may be used.

[0055] The hub classification module 530 assigns recommended types to the hubs in the subset identified by the hub selection module 520. The hub classification module 530 may define the expected throughout of each selected hub based on the itineraries that include the hub as either an origin or destination of a VTOL-serviced leg. The throughput may be an average number of requests serviced per hour, per day, etc. Alternatively, the throughput may be an expected maximum number of requests serviced in a given time period (e.g., the number of expected requests in the busiest hour of the day for that hub, which may be different for different hubs).

[0056] In one embodiment, the hub classification module 530 assigns a recommended type to each hub based on the expected throughputs. The types may be selected from a set of pre-determined designs to provide uniformity and reduce design and construction costs. For example, there may be small, medium, and large hub designs, with the capacities to handle take off/landing of one, four, and sixteen VTOL aircraft 120 simultaneously (or approximately simultaneously), respectively. Alternatively, the hub classification module 530 may assign a number of VTOL aircraft 120 that each hub should be able to take off/land simultaneously (or approximately simultaneously) at the hub. In either case, the classification may take into account a prediction of future growth in demand.

[0057] The hub classification module 530 may also indicate how many VTOL charging stations should be available at each hub (including zero). In one embodiment, the charging facilities available are tied to the type of the hub. E.g., a large hub may have four charging stations, a medium hub one, and a small hub zero. Alternatively or additionally, the hub classification module 530 may consider the distance between the hub and other hubs where charging stations are available. For example, a small hub located at the edge of the transport network, a large distance away from other hubs, may include a charging station even though most small hubs do not. In another embodiment, the number or proportion of each type of hub is set by a user (e.g., via the parameter selection module 510) and the hub classification module 530 selects which hubs should be of which type accordingly. For example, if the user indicates that there should be five large hubs, the parameter selection module 510 might select the five hubs in the subset that have the largest throughput as the large hubs, etc.

[0058] The hub visualization module 540 (if included) presents the selected hub locations to the user. In one embodiment, the hub visualization module 540 overlays indicators of the selected hub locations on a map of the geographic region. The type of each hub may be indicated by variations in size, color, shape, or the like of the indicators. For example, each hub location may be indicated by a black circle with the size of the circle corresponding to the type of hub (e.g., a larger circle is a larger hub). Alternatively, the type of hub and/or additional information (e.g., expected throughout) may be provided next to the indicator or in response to the user selecting the indicator (e.g., by clicking on it). Similarly, where the hubs are to be built in multiple phases, a property of the indicators may indicate which phase of construction each hub is in (e.g., the first phase hubs might be red while second phase hubs might be blue, etc.). The hub visualization module 540 may also provide a user interface for altering the selected hub locations. For example, in one embodiment, the user can add, remove, or relocate hubs as well as change the type and construction phase of each hub.

[0059] The hubs store 550 is one or more computer-readable media configured to store the locations for hubs and corresponding data (e.g., types, throughput, etc.). It may also store a local copy of the candidate hub locations and/or estimated demand data for more efficient data processing. Although it is depicted as a single entity within the hub optimization subsystem 230, it may be spread across multiple computing devices.

[0060] FIG. 6 illustrates one embodiment of the route optimization subsystem 240. The route optimization subsystem determines the routing of VTOL aircraft 120 and riders through the transport network. In the embodiment shown in FIG. 6, the route optimization subsystem 240 includes a parameter selection module 610, a flow modelling module 620, a route visualization module 630, and a routing data store 640. In other embodiments, the route optimization subsystem 240 contains different and/or additional elements. In addition, the functions may be distributed among the elements in a different manner than described.

[0061] The parameter selection module 610 (like its counterparts in the candidate hub identification subsystem 220 and hub optimization subsystem 230) provides a user interface for defining various parameters to be used in modelling the transport network. In one embodiment, the definable parameters include VTOL parameters and objectives. The VTOL parameters may include the number of available VTOL aircraft 120 and, where multiple types are available, their type or types. For each VTOL type, the VTOL parameters may include en route speed, time to ascend, number of seats, whether the VTOL aircraft is autonomous, maximum flying range, battery consumption rate when cruising, battery

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consumption for take-off and landing, battery re-charging rate, whether the battery may be switched at a hub and how long switching takes, and the like. In situations where the routing is being performed for an operational transport network (e.g., in real time or substantially in real time), the parameter selection module 610 may determine some or all of the parameters from data available from the VTOLs 120 and/or hub management systems 130.

[0062] The objective may be to: (1) maximize the number of people transported; (2) maximize use of VTOL aircraft 120 (e.g., use as few VTOL aircraft as possible while minimizing time each spends on the ground); or (3) minimize the total costs of operations, including passenger movement costs (e.g., a per-minute penalty for itineraries longer than the minimum possible), VTOL usage costs (e.g., a penalty for under-utilized VTOL legs), and VTOL aircraft repositioning costs (either to other hubs or within a hub, such as from a landing pad to a storage area). Other objectives and VTOL parameters may also be used.

[0063] The flow modelling module 620 models the flow of VTOL aircraft 120 and riders through the transport network, trying to maximize efficiency in view if the selected objective. In various embodiments, the flow modelling module 620 discretizes time into segments (e.g., one minute, five minutes, etc.) and calculates an optimum or substantially optimum routing for the fleet of VTOLs 120 for each segment. The flow modelling module 620 solves the resulting multi-commodity network flow problem (riders and VTOL aircraft 120 are both commodities in the model) to determine how each VTOL aircraft should be routed to meet the selected objective.

[0064] In one embodiment, the network flow model is defined as follows:

M: The set of VTOL aircraft.
N: The set of all nodes.
P: The set of passengers.
H: The set of hubs.
SS_{iiii}^{nn}: The supply (+) or demand (-) or transit (0) of number of passengers o group n at hub i at time t.
VV_{iiii}: The supply (+) or demand (-) or transit (0) of number of VTOL aircraft at hub i at time t.
$(iiii, jji\bar{i})$: Arc that travels from hub i at time t and arrives at hub j at time $i\bar{t}$.
$In(it)$: The set of arcs coming into hub i at time t.
$Out(it)$: The set of arcs going out from hub i at time t.
A: The set of all arcs (flight arcs and ground arcs).
TA: The set of VTOL transit arcs.
GG_{ii}: The set of ground arcs for the i^{th} hub.
U: The set of arcs for requests served by ground-based transport.
T: The set of all time periods.

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x_{it}^{m}: Whether VTOL aircraft m travels arc i.

y_{it}^{p}: The number of passengers in group p that travels arc i.

z_{it}^{m}: The battery level of VTOL aircraft m at time t.

EE_{it}: The battery consumption (if flying) or charging (if on the ground) for a VTOL aircraft to travel arc i.

VC: The passenger capacity of a VTOL aircraft.

$HHHH_{it}$: The capacity of the i^{th} hub.

B: The max battery level of a VTOL aircraft.

RR_{it}: The cost of repositioning a VTOL aircraft by arc i.

HH_{it}: The cost of travelling arc i.

[0065] Using the above definitions, the model may be defined by the following constraints:

$$\max \quad \sum_{p\in P}\sum_{i\in FA} y_i^p \tag{1}$$

$$\text{s.t.} \quad -\sum_{j\in In(it)} y_j^p + \sum_{k\in Out(it)} y_k^p = S_{it}^p \qquad \forall i \in N, \forall t \in T, \forall p \in P \tag{2}$$

$$V_{i1} - \sum_{m\in M}\sum_{a\in Out(it)} x_a^m = 0 \qquad \forall i \in H \tag{3}$$

$$\sum_{a\in Out(it)} x_a^m - \sum_{b\in In(it)} x_b^m = 0 \qquad \forall i \in H, t \in T, \forall m \in M \tag{4}$$

$$\bar{V}_{iT} + \sum_{m\in M}\sum_{b\in In(it)} x_b^m = 0 \qquad \forall i \in H \tag{5}$$

$$\sum_{m\in M} x_i^m \le HC_j \qquad \forall i \in G_j, \forall j \in H \tag{6}$$

$$\sum_{p\in P} y_j^p \le \sum_{m\in M} x_j^m \qquad \forall j \in A \tag{7}$$

$$x_a^m \in \{0,1\} \qquad \forall a \in A \tag{8}$$

$$y_a^p \in \{0,1\} \qquad \forall a \in A \tag{9}$$

[0066] The network flow module 620 may solve the model to meet a specified objective, such as:

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1. Max time savings

$$\max \sum_{p \in P} (T^p - \sum_{i \in A} T_i y_i^p) \tag{10}$$

2. Max VTOL utilization

$$\max \quad \sum_{m \in M} x^m \tag{11}$$

$$x^m \leq \sum_{a \in FA} x_a^m, \quad \forall m \in M \tag{12}$$

3. Minimize total cost (traveling cost, repositioning cost)

$$min \quad \sum_{p \in P} \sum_{i \in TA} R_i (x_i^p - y_i^p) + \sum_{p \in P} \sum_{i \in A} C_i y_i^p + \sum_{m \in M} q^m \tag{13}$$

$$x_a^m \leq q^m \qquad \forall a \in TA, \forall m \in M \tag{14}$$

[0067] The model used by the network flow module 620 may also be defined as a path-based model:

$$\min \quad \sum_{r \in R} u^r \tag{15}$$

$$\text{s.t.} \quad \sum_{p \in P(r)} y_p^r + u^r = 1 \qquad \forall r \in R \tag{16}$$

$$\sum_{r \in R} \sum_{p \in P(r)} \delta_{ij}^p y_p^r \leq \sum_{v \in V} C^v \sum_{\bar{p} \in P(v)} \delta_{ij}^{\bar{p}} x_{\bar{p}}^v \qquad \forall ij \in A \tag{17}$$

$$\sum_{\bar{p} \in P(v)} x_{\bar{p}}^v = 1 \qquad \forall v \in V \tag{18}$$

$$\sum_{v \in V} \sum_{\bar{p} \in P(v)} \delta_{ij}^{\bar{p}} x_{\bar{p}}^v \leq HC_{ij} \qquad \forall ij \in G \tag{19}$$

$$x_{\bar{p}}^v \in \{0,1\} \qquad \forall p \in P(v) \tag{20}$$

$$y_p^r \in \{0,1\} \qquad \forall a \in A \tag{21}$$

$$u^r \in \{0,1\} \qquad \forall r \in R \tag{22}$$

which results in a reduced cost per column of

$$-\sum_{ij \in A} \alpha_{ij} C^v \delta_{ij}^{\bar{p}} - \sum_{ij \in G} \gamma_{ij} C^v \delta_{ij}^{\bar{p}} - \beta_v \tag{23}$$

[0068] Thus, the network flow module 620 can determines how to route VTOL aircraft 120 through the transport network by finding the shortest path using negative weights and fuel constraints. In this embodiment, the ground arcs have weights of $-\alpha_{ij} C^v - \gamma_{ij}$ and other

arcs will have the weights $-\alpha\alpha_{iiit}HH^{vv}$. In one embodiment, the network flow module 620 considers servicing each transport request via VTOL and each of multiple modes of ground transportation. The network flow module 620 may determine which mode of transport (including VTOL) is likely to be used to service each request. The network flow module 620 may calculate a probability of each request being serviced by each mode of transport based on factors such as: the origin, the destination, the time, convenience (e.g., ingress and egress times), demographics, and the like. In other embodiments, different models for optimizing the routing may be used.

[0069] The route visualization module 630 presents the results of modelling the flow of VTOL aircraft 120 and riders within the transport network to the user. In one embodiment, the results are presented as a set of summary statistics including the number of VTOL aircraft 120 in the fleet, a VTOL utilization percentage (e.g., the percentage of available seats on VTOL legs that were filled), an average time saved for requests serviced by VTOL aircraft (e.g., as a percentage of the ground-only equivalent time), the total number of riders served by VTOL aircraft in the period modelled. In other embodiments, the summary statistics may include different or additional information.

[0070] In addition, the route visualization module 630 may present a timeline indicating how demand varied by hub and over time. In one embodiment, if the user selects a particular time (e.g., by clicking on the corresponding point on the timeline), the route visualization module 630 presents a visualization of state of the transport network at that time, such as by overlaying the flight path of each VTOL aircraft 120 in the air at that point over a map of the geographic area Furthermore, if the user selects a hub, the route visualization module 630 may provide information about the selected hub, such as a number of incoming and outgoing VTOL aircraft 120, a number of passengers waiting to board a VTOL aircraft at the hub, a number of unoccupied landing pads at the hub, and the like. Similarly, if the user selects a VTOL flightpath, information about the corresponding VTOL aircraft 120 and the flightpath may be shown (e.g., an identifier of the particular VTOL aircraft, identifiers of the riders currently being serviced, origin and destination hubs, battery charge remaining, and time remaining to arrival).

[0071] The visualizations provided by the route visualization module 630 may help the user gain a deeper understanding of the transport network and identify potential problems and improvements before construction of the actual infrastructure begins. For example, the user may be able to identify potential choke points in the transport network, either in the form of overburdened hubs or time periods where demand is likely to exceed the number of available

VTOL aircraft 120. The visualizations may also help the user understand how much time will be saved for riders and how many riders will be served, which in turn may be used to estimate how traffic congestion may be alleviated.

[0072] The routing data store 640 stores data used and/or generated by the route optimization subsystem. In one embodiment, the routing data store 640 stores the results of each simulation performed by the flow modelling module 620. Thus, a user may perform multiple simulations using different parameters and then compare the results at a later time. The routing data store 640 may additionally or alternatively store local copies of the data used to model the transport network, such as the hub locations generated by the hub optimization subsystem 230 and the demand data generated by the demand estimation subsystem 210.

COMPUTING SYSTEM ARCHITECTURE

[0073] FIG. 7 is a high-level block diagram illustrating an example computer 700 suitable for use within the computing environment 100. The example computer 700 includes at least one processor 702 coupled to a chipset 704. The chipset 704 includes a memory controller hub 720 and an input/output (I/O) controller hub 722. A memory 706 and a graphics adapter 712 are coupled to the memory controller hub 720, and a display 718 is coupled to the graphics adapter 712. A storage device 708, keyboard 710, pointing device 714, and network adapter 716 are coupled to the I/O controller hub 722. Other embodiments of the computer 700 have different architectures.

[0074] In the embodiment shown in FIG. 7, the storage device 708 is a non-transitory computer-readable storage medium such as a hard drive, compact disk read-only memory (CD-ROM), DVD, or a solid-state memory device. The memory 706 holds instructions and data used by the processor 702. The pointing device 714 is a mouse, track ball, touch-screen, or other type of pointing device, and is used in combination with the keyboard 710 (which may be an on-screen keyboard) to input data into the computer system 700. The graphics adapter 712 displays images and other information on the display 718. The network adapter 716 couples the computer system 700 to one or more computer networks.

[0075] The types of computers used by the entities of FIGS. 1 through 6 can vary depending upon the embodiment and the processing power required by the entity. For example, the transport services management system 110 might include multiple computers 700 working together to provide the functionality described. Furthermore, the computers 700

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can lack some of the components described above, such as keyboards 710, graphics adapters 712, and displays 718.

EXAMPLE METHODS

[0076] FIG. 8 illustrates one embodiment of a method 800 for planning an aviation transport network. The steps of FIG. 8 are illustrated from the perspective of the transport network management system 110 performing the method 800. However, some or all of the steps may be performed by other entities or components. In addition, some embodiments may perform the steps in parallel, perform the steps in different orders, or perform different steps.

[0077] In the embodiment shown in FIG. 8, the method 800 begins with the transport network management system 110 estimating 810 demand for long-distance (e.g., 20 to 120 miles) transport services. The estimated demand is a set of hypothetical transport requests, each including an origin, a destination, and a request time. As described previously, the hypothetical transport requests may be based on historical requests for long-distance transport services using ground-based transportation. In one embodiment, the historical requests are used as the hypothetical requests. In another embodiment, a set of hypothetical transport requests is generated with a similar distribution as the historical requests, with adjustments applied for factors such as expected population growth, expected increase in demand once VTOL aircraft 120 become available, and the like.

[0078] The transport network management system 110 identifies 820 the candidate locations for hubs based on the estimated demand. As described previously, the transport network management system 110 may cluster the origins and destinations of transport requests (e.g., using k-mean clustering) and identify 820 the centroid of each cluster as a candidate location. In one embodiment, the transport network management system 110 identifies 820 one hundred candidate locations for hubs. In another embodiment, the number of hubs to identify is configurable by the user. The user may also be able to manually select or adjust one or more of the candidate locations.

[0079] The transport network management system 110 selects 830 a subset of the candidate locations as the locations for hubs. As described previously, the transport network management system 110 may select 830 the locations of the hubs to achieve one or more objectives, such as maximizing VTOL coverage, maximizing the reduction in travel time across the network, or minimizing a pre-defined cost function (e.g., to balance VTOL coverage with reductions in travel time). In one embodiment, the selected 830 locations are

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divided into different phases to be constructed at different times and which may serve different goals. For example, an initial twenty-five hubs might aim to maximize VTOL coverage while the next ten might aim to maximize savings in travel time. The number of hubs and phases may be predetermined or configurable by the user. The hubs may also be of one or more types (e.g., large, medium, and small, each with a different number of landing pads, charging stations, etc.). In some embodiments, the user may also manually set or adjust the location and/or type selected for one or more hubs.

[0080] The transport network management system 110 calculates 840 route optimization statistics based on the selected information. In one embodiment, the user defines additional parameters, such as the number of VTOL aircraft 120 and information about the VTOL aircraft (e.g., number of seats, cruising speed, time required for take-off and landing, battery capacity, etc.). The transport network planning management 110 determines the optimal routing for the VTOL aircraft 120 to meet the hypothetical demand and calculates 840 corresponding routing information. The route optimization statistics may include a percentage of the requests served by a VTOL aircraft 120, the total time saved relative to using ground-based transportation alone, a total number of people served, an average number of empty seats on VTOL aircraft when flying, and the like. In other embodiments, different or additional information may be included in the route optimization statistics.

[0081] The transport network management system 110 presents 850 a visualization of the transport network to a user. In one embodiment, the visualization includes a map of the geographic area served by the transport network with the hubs overlaid as geometric shapes (e.g., circles) at the corresponding locations. The visualization may also include the route optimization statistics (e.g., in a table). Additionally or alternatively, the visualization may include a time line indicating how demand varies over time, overlay some or all of the VTOL flight paths on the map, provide access to additional information about hubs and VTOL aircraft 120 (e.g., in response to clicking on the corresponding graphical representation in the visualization), and the like, as described previously.

[0082] FIG. 9 illustrates one embodiment of a method 900 for determining routing for a fleet of VTOLs 120 within a transport network. The steps of FIG. 9 are illustrated from the perspective of the transport network management system 110 performing the method 900. However, some or all of the steps may be performed by other entities or components. In addition, some embodiments may perform the steps in parallel, perform the steps in different orders, or perform different steps.

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[0083] FIG. 9 illustrates a single iteration of the method 900. In one embodiment of an active transport network, the method 900 is repeated periodically (e.g., every minute, every five minutes, etc.) to update the routing data for the fleet of VTOLs 120 based on the current conditions. This may enable efficient use of the fleet, even in scenarios where there is a sudden change in conditions. For example, an unexpected failure in another mode of transport (e.g., a subway system shutting down due to an accident) may result in a sudden surge in requests for transport services that may be serviced by VTOL 120, altering the optimal routing for the fleet. Thus, iterating the method 900 may provide advantages including increasing the amount of time saved by riders, reduce the total amount of power used, reduce wear and tear on the VTOLs 120, and the like.

[0084] In the embodiment shown in FIG. 9, the method 900 begins with the parameter selection module 610 retrieving 910 current VTOL and routing data. The VTOL data is information about each of the VTOLs 120 and may include: a current location, whether the VTOL is on the ground or in the air, a current battery level, a maximum battery level, and the like. The VTOL data may be received from the VTOLs 120 (e.g., via a wireless connection) or estimated based on last know values (e.g., as reported by a hub management system 130 when the VTOL 120 was last connected to charge) and the routing data (e.g., a VTOL 120 that is in the air may be assumed to travel along an instructed route at a typical air speed to estimate its current location). The routing data is information about the routes assigned to each VTOL 120. A route may include information such as: a destination, way points to visit en route, a time to depart, a speed to fly at, an amount of time to spend charging before departure or after arrival, a number (and the identity) of riders to carry, and the like. The routing data may be retrieved 910 from a data store (e.g., the routing data store 640).

[0085] The parameter selection module 610 also retrieves 920 current demand data. The current demand data includes requests for transport services that have already been sent by users. In one embodiment, the current demand data is set a set of transport requests received from users (e.g., submitted from client devices 140), each including an origin, a destination, and a time of request.

[0086] The parameter selection module 610 supplements 930 the current demand data with an estimate of future demand. The estimate of future demand may be generated using the demand estimation subsystem as described above, with reference to FIG. 3. The current demand data may be used as an input to the model used by the demand estimation subsystem 210. For example, if the current demand is higher than usual for a given day and time, this may indicate that demand may continue to be higher than normal. In one embodiment, the

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estimate of future demand is a set of hypothetical requests for transport services, each including an origin, a destination, and a time of request within a given time period (e.g., the next fifteen minutes, the next hour, the next four hours etc.). The estimate of future demand may be combined with the current demand data to generate a single set of transport requests (both actual and hypothetical/expected). Thus, the demand data may represent an estimate of demand for the time period that includes both transport requests that have already been received and a prediction of future transport requests.

[0087] The route optimization subsystem 240 updates 940 the routing data based on the demand data. In one embodiment, the flow modelling module 620 determines the optimum routing based on the demand data as well as the VTOL and routing data. This may be done using the optimization approaches described above, with reference to FIG. 6. The input to the route optimization subsystem 240 may include the retrieved 910 VTOL data, the demand data, weather data, and the like. Based on the updated routing data, the route optimization subsystem 240 may send routing instructions to some or all of the VTOLs 120. For example, the instructions might direct a VTOL 120 to fly to a particular hub, charge its battery for a specified time, pick up specified riders, and perform other suitable activities to optimize the use of the VTOLs in the transport network.

ADDITIONAL CONSIDERATIONS

[0088] Some portions of above description describe the embodiments in terms of algorithmic processes or operations. These algorithmic descriptions and representations are commonly used by those skilled in the data processing arts to convey the substance of their work effectively to others skilled in the art. These operations, while described functionally, computationally, or logically, are understood to be implemented by computer programs comprising instructions for execution by a processor or equivalent electrical circuits, microcode, or the like. Furthermore, it has also proven convenient at times, to refer to these arrangements of functional operations as modules, without loss of generality.

[0089] As used herein, any reference to "one embodiment" or "an embodiment" means that a particular element, feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment. The appearances of the phrase "in one embodiment" in various places in the specification are not necessarily all referring to the same embodiment.

[0090] Some embodiments may be described using the expression "coupled" and "connected" along with their derivatives. It should be understood that these terms are not

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intended as synonyms for each other. For example, some embodiments may be described using the term "connected" to indicate that two or more elements are in direct physical or electrical contact with each other. In another example, some embodiments may be described using the term "coupled" to indicate that two or more elements are in direct physical or electrical contact. The term "coupled," however, may also mean that two or more elements are not in direct contact with each other, but yet still co-operate or interact with each other. The embodiments are not limited in this context.

[0091] As used herein, the terms "comprises," "comprising," "includes," "including," "has," "having" or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article, or apparatus that comprises a list of elements is not necessarily limited to only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus. Further, unless expressly stated to the contrary, "or" refers to an inclusive or and not to an exclusive or. For example, a condition A or B is satisfied by any one of the following: A is true (or present) and B is false (or not present), A is false (or not present) and B is true (or present), and both A and B are true (or present).

[0091a] Any discussion of documents, acts, materials, devices, articles or the like which has been included in the present specification is not to be taken as an admission that any or all of these matters form part of the prior art base or were common general knowledge in the field relevant to the present disclosure as it existed before the priority date of each of the appended claims.

[0092] In addition, use of the "a" or "an" are employed to describe elements and components of the embodiments. This is done merely for convenience and to give a general sense of the disclosure. This description should be read to include one or at least one and the singular also includes the plural unless it is obvious that it is meant otherwise.

[0093] Upon reading this disclosure, those of skill in the art will appreciate still additional alternative structural and functional designs for a system and a process for planning a transport network and coordinating transport services within that network. Thus, while particular embodiments and applications have been illustrated and described, it is to be understood that the described subject matter is not limited to the precise construction and components disclosed herein and that various modifications, changes and variations which will be apparent to those skilled in the art may be made in the arrangement, operation and details of the method and apparatus disclosed. The scope of protection should be limited only by the following claims.

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CLAIMS

1. A method implemented by a computer system to utilize real-time data to dynamically determine charging times of an aircraft to perform on-demand routing, the method comprising:

identifying a service objective for a plurality of vertical take-off and landing (VTOL) aircraft;

retrieving real-time VTOL data from the plurality of VTOL aircraft, the VTOL data including current locations, battery consumption rates, battery charging rates, and current battery levels of the plurality of VTOL aircraft;

generating an estimate of demand for passenger transport services during a given time period;

determining, based on the estimate of demand, the current battery levels, and the service objective, a route for each of the plurality of VTOL aircraft, each route specifying a destination, any way points to visit while traveling to the destination, an amount of time to spend charging, and a time to depart; and

sending routing instructions to at least a subset of the VTOL aircraft, the routing instructions based on the determined route for each of the VTOL aircraft in the subset,

wherein determining the amount of time to spend charging for each of the plurality of VTOL aircraft includes processing the current battery levels, the consumption rates, and the charging rates of the battery of the VTOL aircraft, and

wherein the routing instructions direct the flight of at least one of the VTOL aircraft in the subset to charge for the amount of time.

2. The method of claim 1, wherein the service objective is at least one of:

maximizing a number of people transported by VTOL aircraft;

minimizing a total amount of time spent on the ground by VTOL aircraft; or maximizing an average number of people in each VTOL aircraft when the VTOL aircraft in in the air.

3. The method of claim 1 or 2, wherein generating the estimate of demand comprises:

retrieving current demand data, the current demand data indicating unfulfilled requests for passenger transport services already made by riders; and

supplementing the current demand data with an estimate of requests for passenger

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transport services that will be received in the given time period.

4. The method of any of the preceding claims, wherein the estimate of demand comprises a plurality of requests for passenger transport services, each request identifying an origin and a destination.

5. The method of any of the preceding claims, wherein the determining of the route for each of the plurality of VTOL aircraft comprises

providing the VTOL data and estimated demand as input to a network flow model; and

solving the network flow model in view of the identified service objective.

6. A computer program comprising machine-readable instructions that, when executed by one or more processors, causes the one or more processors to perform operations to utilize real-time data to dynamically determine charging times of an aircraft to perform on-demand routing, the computer program comprising:

identifying a service objective for a plurality of vertical take-off and landing (VTOL) aircraft;

retrieving real-time VTOL data from the plurality of VTOL aircraft, the VTOL data including current locations, battery consumption rates, battery charging rates, and current battery levels of the plurality of VTOL aircraft;

generating an estimate of demand for passenger transport services during a given time period;

determining, based on the estimate of demand, the current battery levels, and the service objective, a route for each of the plurality of VTOL aircraft, each route specifying a destination, any way points to visit while traveling to the destination, an amount of time to spend charging, and a time to depart; and

sending routing instructions to at least a subset of the VTOL aircraft, the routing instructions based on the route for each of the plurality of VTOL aircraft in the subset,

wherein determining the amount of time to spend charging for each of the plurality of VTOL aircraft includes processing the current battery levels, the consumption rates, and the charging rates of the battery of the VTOL aircraft, and

wherein the routing instructions direct the flight of at least one of the VTOL aircraft in the subset to charge for the amount of time.

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7. The computer program of claim 6, wherein the service objective is at least one of: maximizing a number of people transported by VTOL aircraft; minimizing a total amount of time spent on the ground by VTOL aircraft; or maximizing an average number of people in each VTOL aircraft when the VTOL aircraft in in the air.

8. The computer program of claim 6 or 7, wherein generating the estimate of demand comprises:

retrieving current demand data, the current demand data indicating unfulfilled requests for passenger transport services already made by riders; and

supplementing the current demand data with an estimate of requests for passenger transport services that will be received in the given time period.

9. The computer program of any of claims 6 to 8, wherein the estimate of demand comprises a plurality of requests for passenger transport services, each request identifying an origin and a destination.

10. The computer program of any of claims 6 to 9, wherein the determining of a route for each of the plurality of VTOL aircraft comprises:

providing the VTOL data and estimated demand as input to a network flow model; and

solving the network flow model in view of the identified service objective.

11. A computer system to utilize real-time data to dynamically determine charging times of an aircraft to perform on-demand routing, the computer system comprising:

one or more hardware processors; and

a computer-readable storage medium comprising executable computer program code, the computer program code when executed causing the one or more processors to perform operations including:

identifying a service objective for a plurality of vertical take-off and landing (VTOL) aircraft;

retrieving real-time VTOL data from the plurality of VTOL aircraft, the VTOL data including current locations, battery consumption rates, battery charging rates, and current battery levels of the plurality of VTOL aircraft;

generating an estimate of demand for passenger transport services during a given time period;

determining battery levels of each of the plurality of VTOL aircraft;

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determining, based on the estimate of demand, the battery levels, and the service objective, a route for each of the plurality of VTOL aircraft, each route specifying a destination, any way points to visit while traveling to the destination, an amount of time to spend charging, and a time to depart; and

sending routing instructions to at least a subset of the VTOL aircraft, the routing instructions based on the routes for each of the VTOL aircraft in the subset,

wherein determining the amount of time to spend charging for each of the plurality of VTOL aircraft includes processing the current battery levels, the consumption rates, and the charging rates of the battery of the VTOL aircraft, and

wherein the routing instructions direct the flight of at least one of the VTOL aircraft in the subset to charge for the amount of time.

12. The computer system of claim 11, wherein the service objective is at least one of: maximizing a number of people transported by VTOL aircraft; minimizing a total amount of time spent on the ground by VTOL aircraft; or maximizing an average number of people in each VTOL aircraft when the VTOL aircraft in in the air.

13. The computer system of claim 11 or 12, wherein generating the estimate of demand comprises:

retrieving current demand data, the current demand data indicating unfulfilled requests for passenger transport services already made by riders; and

supplementing the current demand data with an estimate of requests for passenger transport services that will be received in the given time period.

14. The computer system of claim 11, 12 or 13, wherein the estimate of demand comprises a plurality of requests for passenger transport services, each request identifying an origin and a destination.

15. The computer system of any of claims 11 to 14, wherein determining of each of the routes comprises:

providing the VTOL data and estimated demand as input to a network flow model; and

solving the network flow model in view of the identified service objective.

16. The method of any of the preceding claims, wherein the determining of a route for each of the VTOL aircraft comprises:

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determining a plurality of different flows of each of the VTOL aircraft through a transportation network;

selecting, for at least s subset of the plurality of VTOL aircraft, a respective one of the different flows; and

determining each of the routes based on each of the selected flows.

17. The method of claim 16, further comprising:

determining locations of the plurality of vertical take-off and landing (VTOL) aircraft;

determining, based on the estimate of demand, a plurality of passenger transportation requests, each passenger transportation request for travel from a respective origin location to a respective destination location; and

providing the plurality of passenger transportation requests, the locations, and the battery levels to a network flow model, the network flow model configured to concurrently determine each of the routes for each of the plurality of VTOL aircraft by modeling different flows of the plurality of VTOL aircraft through the transportation network.

18. A method implemented by a computer system to utilize real-time data to dynamically determine charging times of an aircraft to perform on-demand routing, the method comprising:

determining locations of a plurality of vertical take-off and landing (VTOL) aircraft;

determining a plurality of passenger transportation requests, each passenger transportation request for travel from a respective origin location to a respective destination location;

determining, in real-time, a battery consumption rate, a battery charging rate, and a current battery level for each of the plurality of VTOL aircraft;

providing the plurality of passenger transportation requests, the locations, and the current battery levels to a network flow model, the network flow model configured to concurrently determine routing data for each of the plurality of VTOL aircraft by modeling different flows of the plurality of VTOL aircraft through a transportation network; and

sending routing instructions to at least a subset of the VTOL aircraft, the routing instructions based on each VTOL aircraft's respective routing data,

wherein the routing instructions direct the flight of at least one of the VTOL aircraft in the subset to charge for an amount of time, and

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wherein determining the amount of time to spend charging for at least one of the VTOL aircraft in the subset includes processing the current battery levels, the consumption rates, and the charging rates of the battery of the VTOL aircraft.

19. The method of claim 18, further comprising determining a service objective for the plurality of VTOL aircraft, wherein the determining of the routing data is further based on the service objective.

20. The method of claim 19, wherein the service objective is at least one of: maximizing a number of people transported by VTOL aircraft; minimizing a total amount of time spent on the ground by VTOL aircraft; or maximizing an average number of people in each VTOL aircraft when the VTOL aircraft is in the air.

21. The method of claim 18, 19 or 20, wherein the network flow model is further configured to, based on the modeling of the different flows of the plurality of VTOL aircraft through the transportation network, determine that a specific VTOL aircraft is to recharge for a specified amount of time before executing a route, and wherein the sending of the routing instructions is based on the determination.

22. The method of any of claims 18 to 21, wherein determining the plurality of passenger transportation requests comprises:

retrieving current demand data, the current demand data indicating unfulfilled requests for passenger transport services already made by riders; and

supplementing the current demand data with an estimate of requests for passenger transport services that will be received in a given time period, wherein the plurality of passenger transportation requests are based on the supplemented current demand data.

23. The method of any of claims 18 to 22, further comprising:

generating a plurality of demand profiles for transportation services;

measuring demand for transportation services; and

identifying which of the plurality of demand profiles is most similar to the measured demand, wherein the plurality of passenger transportation requests are based on the identified demand profile.

24. The method of claim 23, further comprising periodically measuring the demand for

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transportation services, and sending periodic routing instructions to at least a subset of the VTOL aircraft, the periodic routing instructions based on the periodically measured demand.

25. A computer program comprising machine-readable instructions that, when executed by one or more processors, causes the one or more processors to perform operations to utilize real-time data to dynamically determine charging times of an aircraft to perform on-demand routing, the operations comprising:

determining locations of a plurality of vertical take-off and landing (VTOL) aircraft;

determining a plurality of passenger transportation requests, each passenger transportation request for travel from a respective origin location to a respective destination location;

determining, in real-time, a battery consumption rate, a battery charging rate, and a current battery level for each of the plurality of VTOL aircraft;

providing the plurality of passenger transportation requests, the locations, and the current battery levels to a network flow model, the network flow model configured to concurrently determine routing data for each of the plurality of VTOL aircraft by modeling different flows of the plurality of VTOL aircraft through a transportation network; and

sending routing instructions to at least a subset of the VTOL aircraft, the routing instructions based on each VTOL aircraft's respective routing data,

wherein the routing instructions direct the flight of at least one of the VTOL aircraft in the subset to charge for an amount of time, and

wherein determining the amount of time to spend charging for at least one of the VTOL aircraft in the subset includes processing the current battery levels, the consumption rates, and the charging rates of the battery of the VTOL aircraft.

26. The computer program of claim 25, the operations further comprising determining a service objective for the routing instructions, wherein the routing data is based on the service objective.

27. The computer program of claim 26, wherein the service objective is at least one of: maximizing a number of people transported by VTOL aircraft; minimizing a total amount of time spent on the ground by VTOL aircraft; or maximizing an average number of people in each VTOL aircraft when the VTOL aircraft is in the air.

28. The computer program of claim 26 or 27, wherein the network flow model is further

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configured to, based on the modeling of the different flows of the plurality of VTOL aircraft through the transportation network, determine that a specific VTOL aircraft is to recharge for a specified amount of time before executing a route, and wherein the sending of the routing instructions is based on the determination.

29. The computer program of claim 26, 27 or 28, wherein determining the plurality of passenger transportation requests comprises:

retrieving current demand data, the current demand data indicating unfulfilled requests for passenger transport services already made by riders; and

supplementing the current demand data with an estimate of requests for passenger transport services that will be received in a given time period, wherein the plurality of passenger transportation requests are determined based on the supplemented current demand data.

30. A computer system to utilize real-time data to dynamically determine charging times of an aircraft to perform on-demand routing, the computer system comprising:

one or more hardware processors; and

a computer-readable storage medium comprising executable computer program code, the computer program code when executed causing the one or more hardware processors to perform operations including:

determining locations of a plurality of vertical take-off and landing (VTOL) aircraft;

determining a plurality of passenger transportation requests, each passenger transportation request for travel from a respective origin location to a respective destination location;

determining, in real-time, a battery consumption rate, a battery charging rate, and a current battery level for each of the plurality of VTOL aircraft;

providing the plurality of passenger transportation requests, the locations, and the current battery levels to a network flow model, the network flow model configured to concurrently determine routing data for each of the plurality of VTOL aircraft by modeling different flows of the plurality of VTOL aircraft through a transportation network; and

sending routing instructions to at least a subset of the VTOL aircraft, the routing instructions based on each VTOL aircraft's respective routing data,

wherein the routing instructions direct the flight of at least one of the VTOL aircraft in the subset to charge for an amount of time, and

wherein determining the amount of time to spend charging for at least one of the

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VTOL aircraft in the subset includes processing the current battery levels, the consumption rates, and the charging rates of the battery of the VTOL aircraft.

31. The system of claim 30, the operations further comprising determining a service objective for the plurality of VTOL aircraft, wherein the determining of the routing data is further based on the service objective.

32. The computer system of claim 31, wherein the service objective is at least one of: maximizing a number of people transported by VTOL aircraft; minimizing a total amount of time spent on the ground by VTOL aircraft; or maximizing an average number of people in each VTOL aircraft when the VTOL aircraft is in the air.

33. The computer system of any of claims 30 to 32, wherein determining the plurality of passenger transportation requests comprises:

retrieving current demand data, the current demand data indicating unfulfilled requests for passenger transport services already made by riders; and

supplementing the current demand data with an estimate of requests for passenger transport services that will be received in a given time period, wherein the determining of the plurality of passenger transportation requests is based on the supplemented demand data.

34. The method of any of claims 18 to 24, wherein the network flow model is configured to model the different flows based on one or more of a passenger capacity of a VTOL aircraft of the plurality of VTOL aircraft, a maximum battery level of a VTOL aircraft of the plurality of VTOL aircraft, a cost of repositioning a VTOL aircraft of the plurality of VTOL aircraft without transporting passengers, a total number of passengers that travel between two identical locations in at least two of the passenger transportation requests.

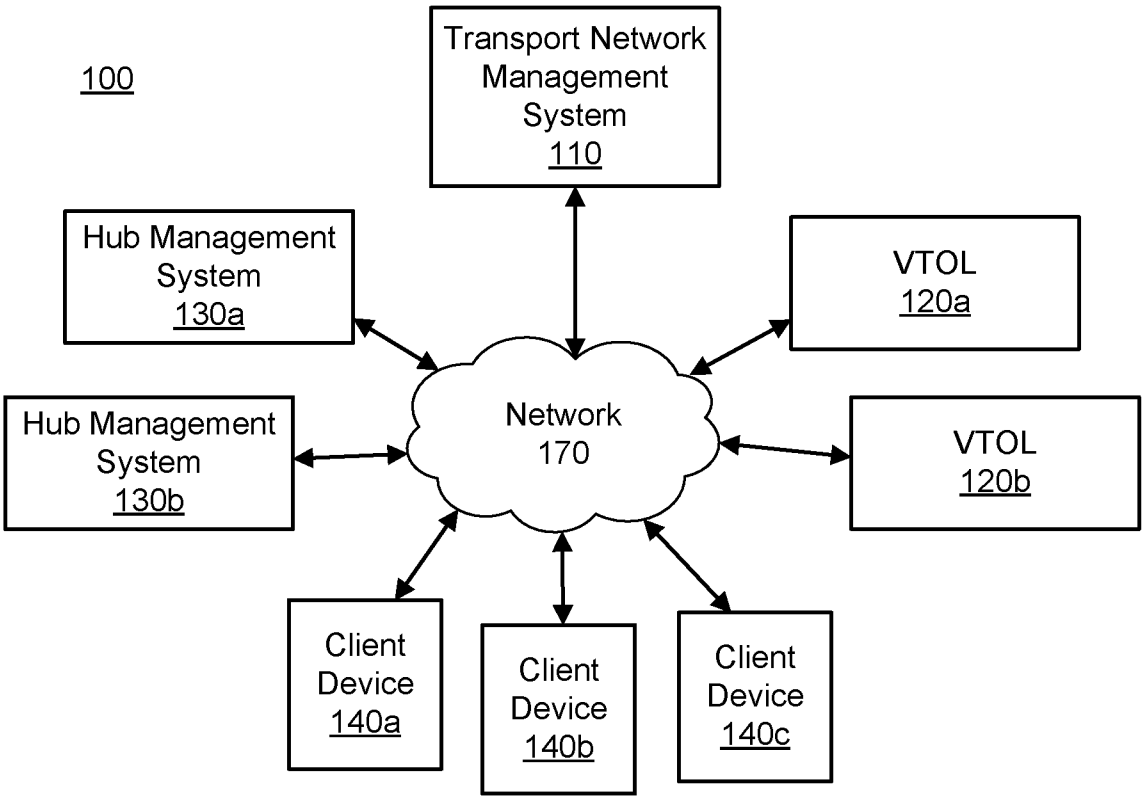
100
Transport Network Management System 110
Hub Management System 130a
VTOL 120a
Network 170
Hub Management System 130b
VTOL 120b
Client Device 140a
Client Device 140b
Client Device 140c

FIG. 1

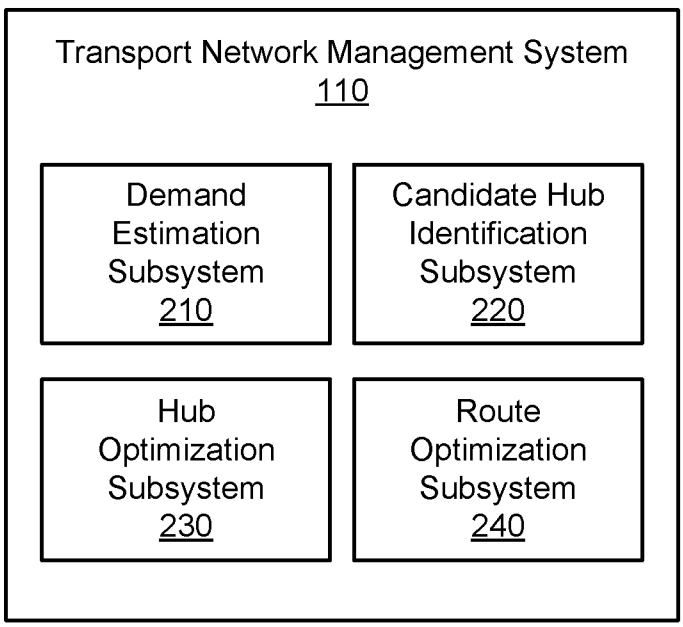
Transport Network Management System 110
Demand Estimation Subsystem 210
Candidate Hub Identification Subsystem 220
Hub Optimization Subsystem 230
Route Optimization Subsystem 240

FIG. 2

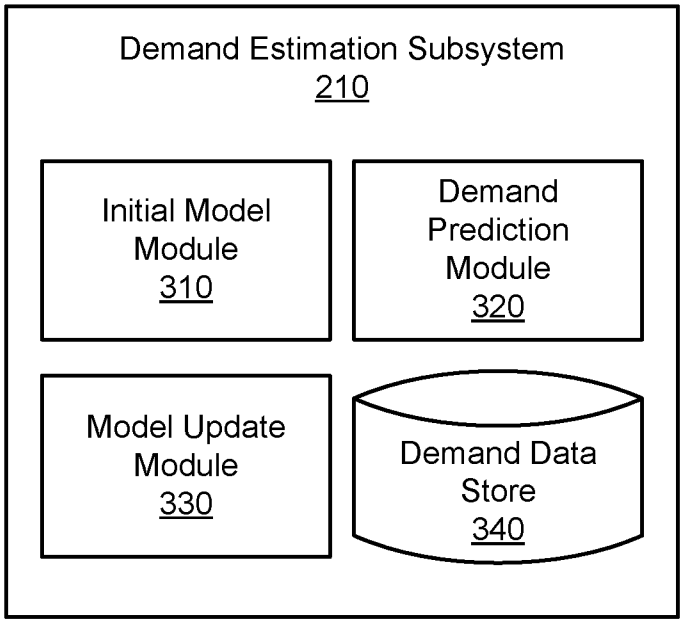
Demand Estimation Subsystem
210
Initial Model Module
310
Demand Prediction Module
320
Model Update Module
330
Demand Data Store
340

FIG. 3

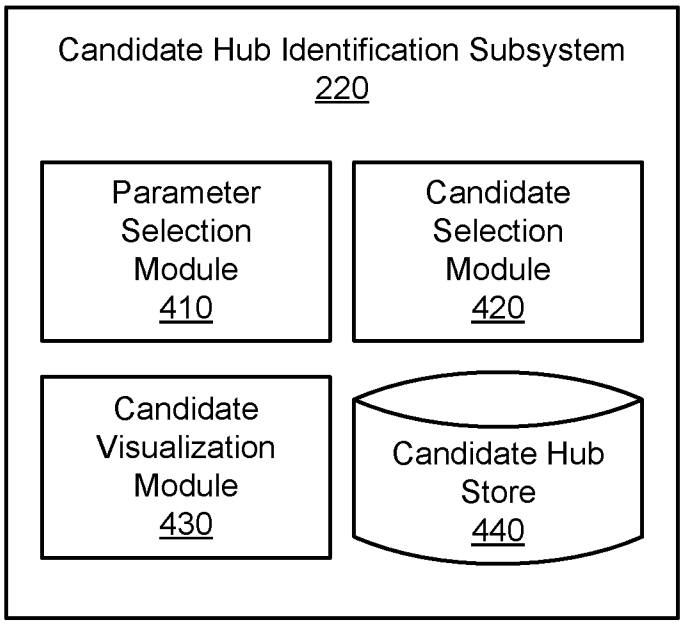
Candidate Hub Identification Subsystem
220
Parameter Selection Module
410
Candidate Selection Module
420
Candidate Visualization Module
430
Candidate Hub Store
440

FIG. 4

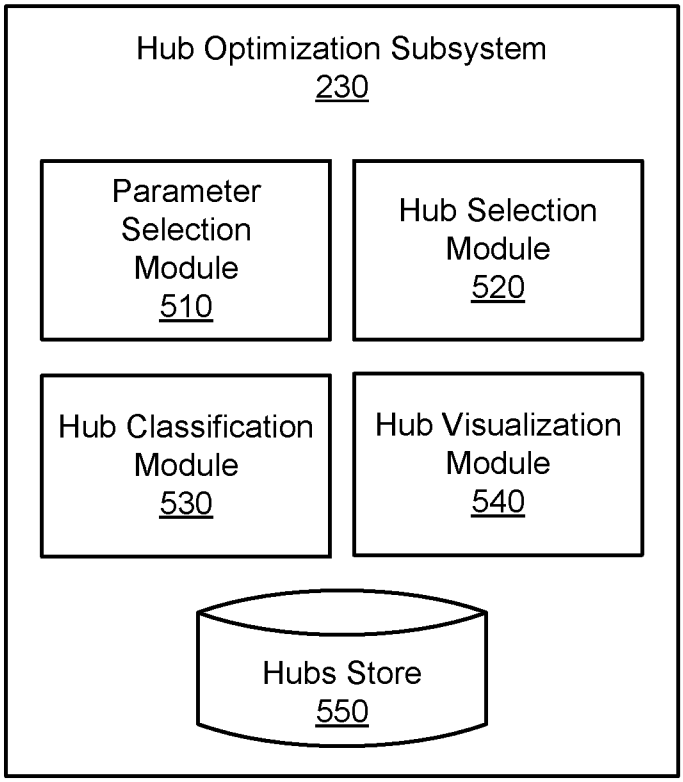
Hub Optimization Subsystem
230
Parameter Selection Module
510
Hub Selection Module
520
Hub Classification Module
530
Hub Visualization Module
540
Hubs Store
550

FIG. 5

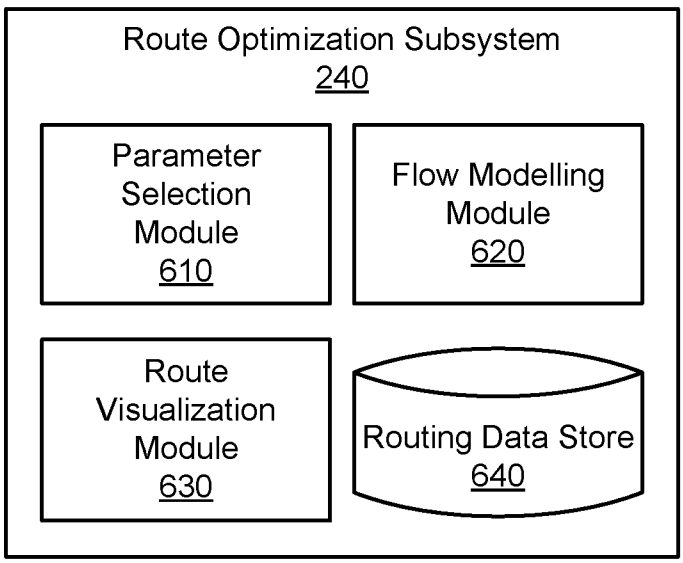
Route Optimization Subsystem
240
Parameter Selection Module
610
Flow Modelling Module
620
Route Visualization Module
630
Routing Data Store
640

FIG. 6

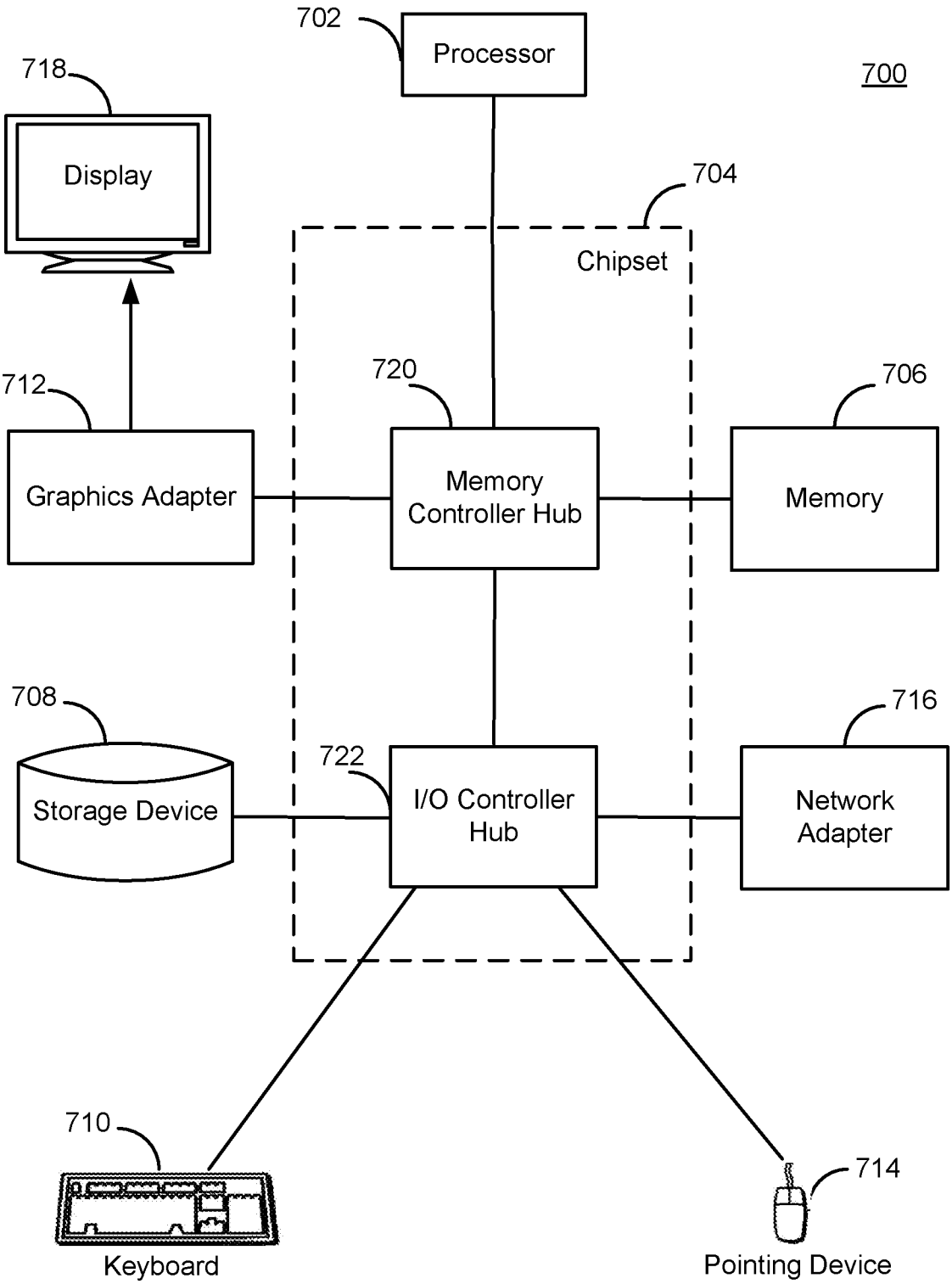
702
Processor
700
718
Display
704
Chipset
712
720
706
Graphics Adapter
Memory Controller Hub
Memory
708
716
722
Storage Device
I/O Controller Hub
Network Adapter
710
714
Keyboard
Pointing Device

FIG. 7

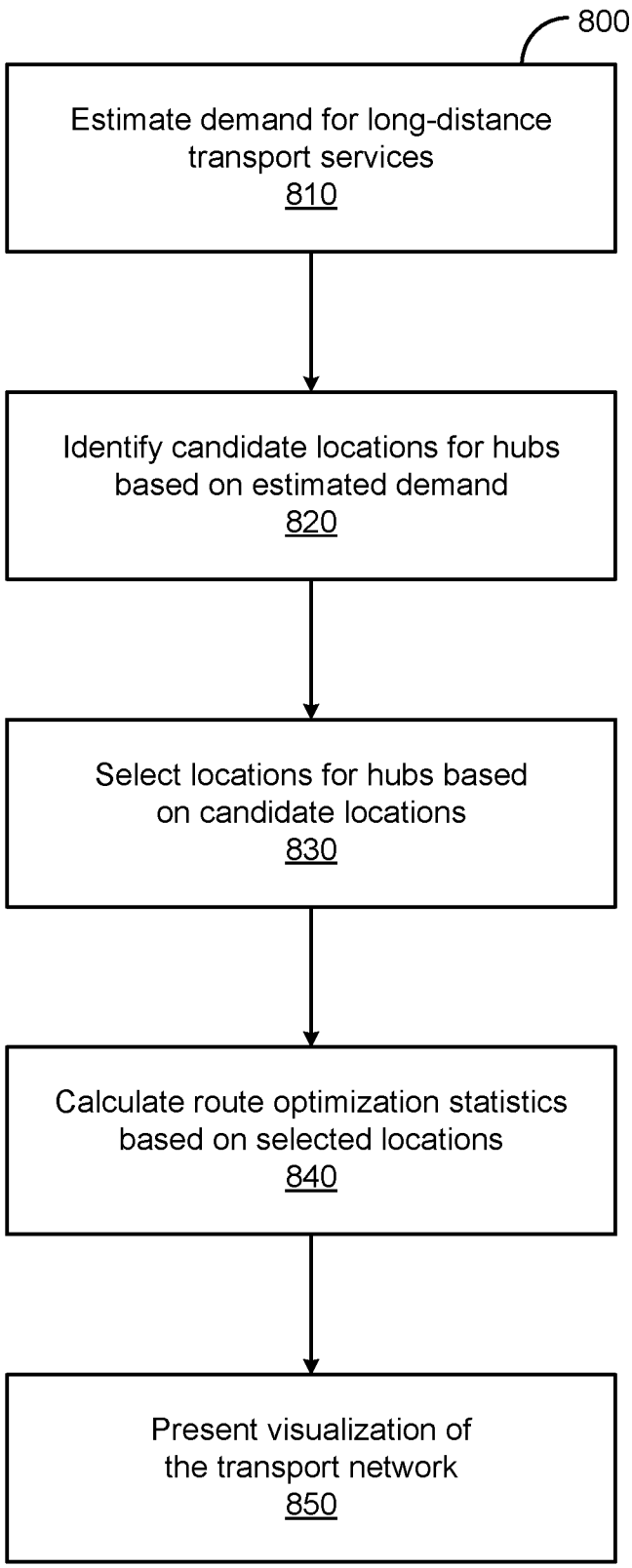
800
Estimate demand for long-distance transport services
810
Identify candidate locations for hubs based on estimated demand
820
Select locations for hubs based on candidate locations
830
Calculate route optimization statistics based on selected locations
840
Present visualization of the transport network
850

FIG. 8

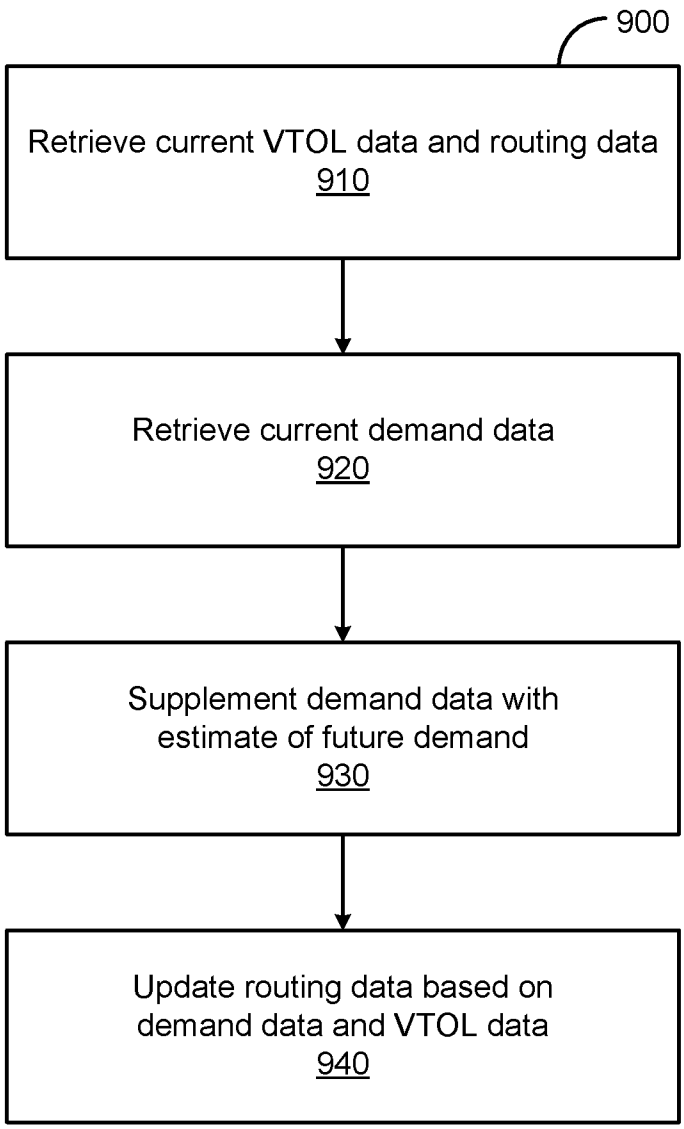
900
Retrieve current VTOL data and routing data
910
Retrieve current demand data
920
Supplement demand data with estimate of future demand
930
Update routing data based on demand data and VTOL data
940

FIG. 9